Non-negative Decomposition of Sea Surface Dynamics from Multi-source Ocean Remote Sensing Data

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1. Abstract

The growing availability of multi-source ocean remote sensing data is a key factor for improving our understanding of upper ocean dynamics, ocean circulation and atmospheric-ocean interactions. Following an ongoing body of work that investigates mesoscale upper ocean dynamics from linear couplings between SST (sea surface temperature) and SSH (sea surface height), we propose a novel observation-driven framework for the identification and characterization of sea surface dynamical modes. It relies on a multi-modal decomposition of SST-SSH relationships. Our findings suggest that upper ocean dynamics may be decomposed as the superimposition of several dynamical modes, rather than mutually exclusive ones as investigated in previous work. Our study stresses the relevance of a non-negative bi-modal additive decomposition to capture the complex space-time variability of mesoscale upper ocean dynamics.

2. Context and motivation

- **Huge exploitaition potential** exists within remote sensing datasets.
- **Mesoscale upper ocean dynamics: local linear coupling between SST and SSH** (Surface Quasi-Geostrophy).

$$\mathcal{F}_H(\widehat{\mathrm{SSH}}) = -\gamma\,|k|^{-1}\,\mathcal{F}_T(\widehat{\mathrm{SST}})$$

However,

- **Upper ocean dynamics: complex system interactions** over a **wide range of spatio-temporal scales.**
- A **single SQG-like linear transfer function** does **not suffice** to **capture the whole mesoscale upper ocean dynamics** of a particular region.
- **SQG-like upper ocean dynamics** are **not well represented** by latent class models.

3. Model

- **Non-negative** decomposition.
- **Dynamical modes** in play **do not exclude each other** but are rather **superimposed**.
- **Generalization** of classical regression models and latent class models.

$$\mathbf{y}_n = \sum_{k=1}^{K} \alpha_{nk}\boldsymbol{\beta}_k\mathbf{x}_n + \omega_n$$

$$\text{s.t.} \begin{cases} \alpha_{nk} \geq 0, & \forall\, k \in 1,K,\ \forall n \in 1,N \\ ||\boldsymbol{\beta}_k||_F = 1, & \forall\, k \in 1,K \end{cases}$$

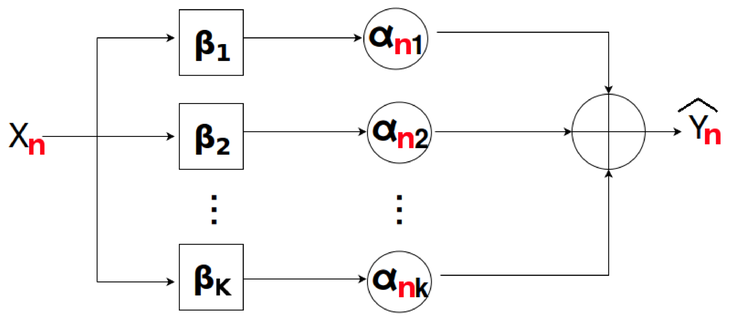


Figure 2: *Model graphical representation.*

4. Application to SSH/SST datasets

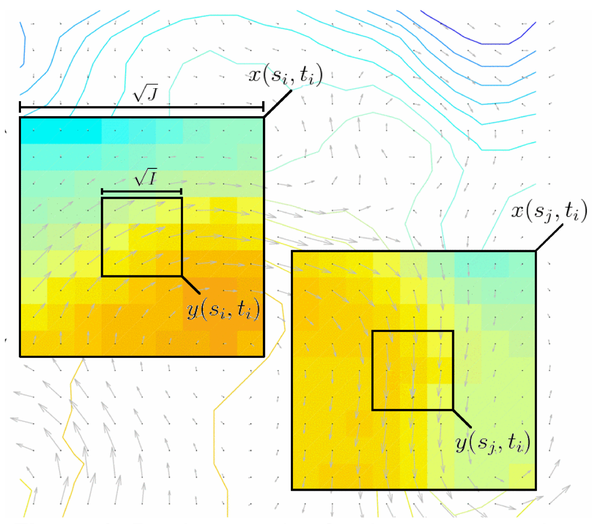


Figure 1: *Patch extraction for dataset generation.*

- Region of Interest: **Agulhas** region.
- **Microwave SST** (OI-SST provided by RSS).
- **Altimeter-derived SSH** (AVISO provided by CLS).
- **Patch-based** dataset generation.
- **Model training: random** set of data from **2004** (4 altimeters available).
- Model **applied daily** to the **whole 2004 dataset.**

5. Results

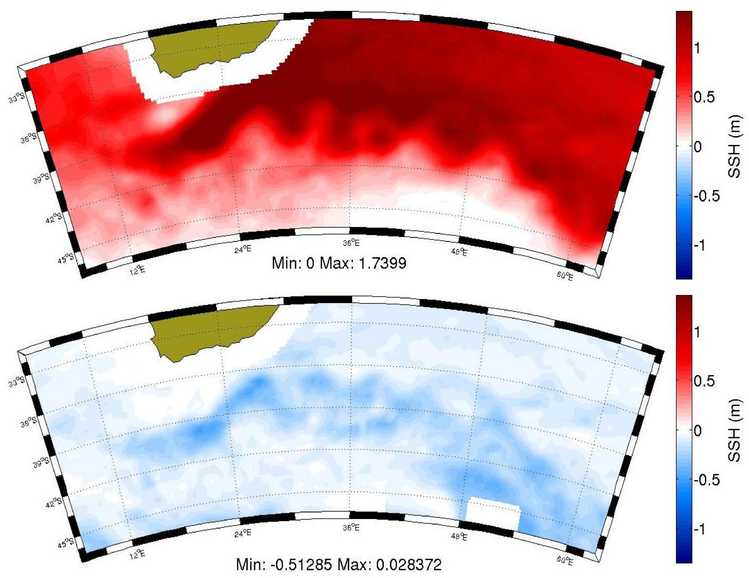


Figure 3: *Mean annual SSH field prediction for each dynamical mode: top, mode 1 (SQG-like mode); bottom, mode 2.*

	SSH	SSH gradient
Latent Regression Model [**2**] ($K=4$)	0.1600	0.1600
Proposed model ($K=1$)	0.1312	0.3164
Proposed model ($K=2$)	0.0297	0.1302

Table 1: *Model performace in terms of relative root mean square reconstruction error (RRMSE).*

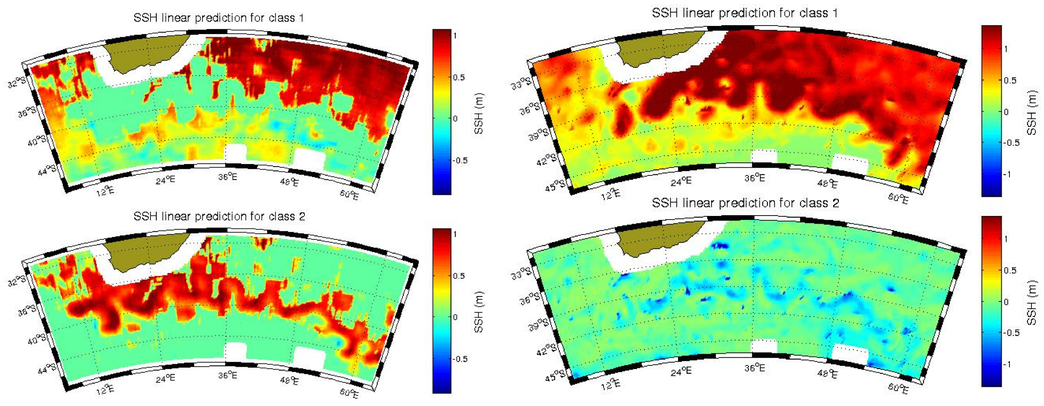


Figure 4: *Comparison of SSH modal predictions for the 1st January 2004. Left, latent regression model **[2]** ; right, proposed model. Top, mode 1 (SQG-like mode); bottom, mode 2.*

Discussion

- **First mode:** captures the **mean north-south gradient** and is **highly correlated to SQG-like dynamics** (R^2>0.95, p<0.001).
- **Second mode: local correction** to mode 1 that captures the **Agulhas current** as a **variation around the mean north-south gradient.**
- **SQG-like mode** accounts for **80% of the spatio-temporal variability**.
- **One order of magnitude reconstruction performance improvement** with respect to latent class model **[2]**.

6. Conclusions

We have proposed a **novel model** characterized by the **continuous superimposition** of dynamical modes. The proposed model has **improved compatibility with locally varying upper ocean dynamics** and allows for the **local characterization of continuous shift between SQG-like and non-SQG dynamics**. As far as future work is concerned, **further analysis of model parameters** and their **physical interpretation** is needed. Applying the propsoed model at a **global scale** appears promising to reveal **shared or differentiating dynamical modes**. Additionally, considering **alternative sources of information** (salinity, ocean color, etc.) is also contemplated. Alternative model formulations, such as **non-linear extensions** or **sparse formulations for mixing coefficients** could prove useful for a variety of applications, most notably in the case of the **prediction/segmentation** of **dynamical systems**.

References

[1] M. López-Radcenco et al., "Non-negative decomposition of linear relationships: Application to multi-source ocean remote sensing data", *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Shanghai, 2016, pp. 4179-4183.*

[2] P. Tandeo et al.,"Segmentation of Mesoscale Ocean Surface Dynamics Using Satellite SST and SSH Observations", *IEEE Transactions on Geoscience and Remote Sensing, vol. 52, no. 7, pp. 4227-4235, July 1 2014.*

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